MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2022/2023 (TERM ID 2210)

EEE 3076 – POWER ELECTRONICS

(LE, EE, CE, NE)

16 FEBRUARY 2023
2:30 p.m – 4.30 p.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 8 pages including cover page with 4 Questions only.

2. Answer ALL questions. All questions carry equal marks and the distributions of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

Question 1

a) Figure Q1 (a) shows a converter circuit used to control power level to a resistive load. The operating switching frequency of the circuit is 30 kHz and the duty cycle is 40%.

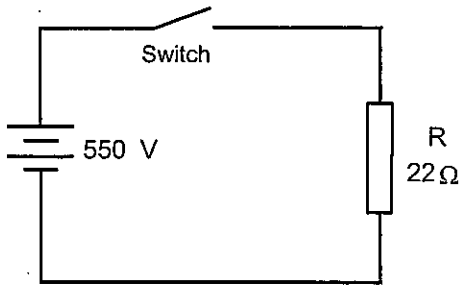

Figure Q1 (a)

(i) Calculate the continuous current through the switch.

[3 marks]

(ii) Select a suitable switch for this application based on datasheets for Switch 1 and Switch 2 given in Appendix A. Explain why; please give two (2) reasons.

[7 marks]

b) A Power MOSFET (Switch 2) with the electrical characteristics as shown below in Appendix A is used as a switch for a DC-DC converter connected to an inductive load. The input voltage is 300 V and the maximum output current is 17 A. The switch is operated at 40 kHz with 60% duty cycle.

(i) Static Loss. [6 marks]

(ii) Dynamic Loss. [6 marks]

(iii) Total Loss. [3 marks]

Continued...

Question 2

Design a rectifier circuit.

Customer Specifications
Input voltage: 400 V, 50 Hz
Output Power: 15 kW
Type of Load: Induction load (inductive large enough to maintain constant output current)

a) Sketch the rectifier circuit

[3 marks]

b) Sketch the waveforms for the input voltage, output voltage, output current and one of the input current waveforms.

[8 marks]

c) Calculate the output voltage and output current.

[6 marks]

d) Calculate the r.m.s value of the input current and the input power. Given power factor is one.

[6 marks]

e) State at least 2 assumptions taken during the rectifier design.

[2 marks]

Continued...

Question 3

A mobile robot required a dc supply, 100V, 600W. A lithium-ion battery 48V, 1kW is used as the power source.

Design a DC-DC Converter for the mobile robot with the following output specifications

Maximum Output voltage ripple: 1 %
Maximum Output current ripple: 1 %
Switching Frequencies: 50 kHz.

a) Sketch the circuit diagram for the proposed DC-DC Converter

[5 marks]

b) Size all the filter components (L and C) for the DC-DC Converter.

[20 marks]

Continued...

Question 4

a) An inverter shown in Figure Q4 is used to supply an RL load. The inverter operates at a duty cycle of 50 % with a frequency of 50 Hz.

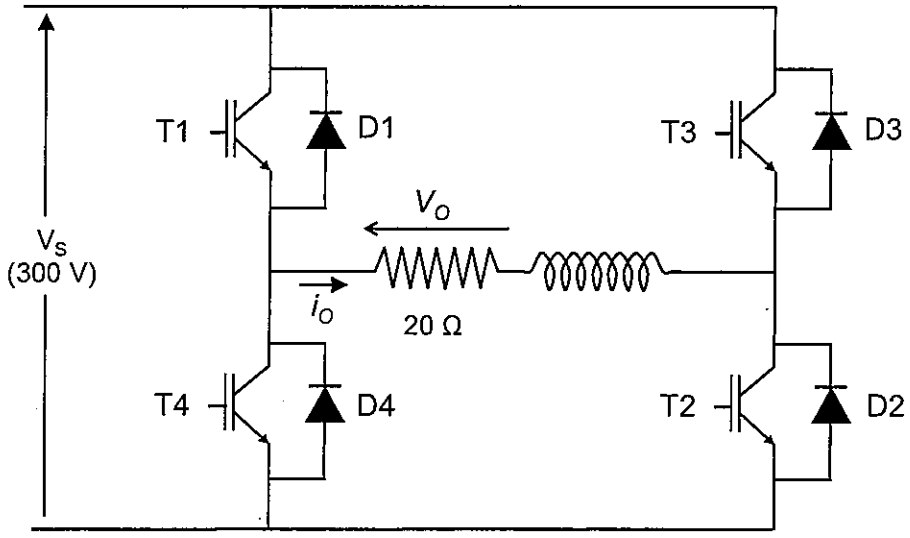

Figure Q4

(i) Calculate the r.m.s voltage for fundamental, 3rd , 5th and 7th Harmonic component.
[8 marks]

(ii) Calculate the output power considering fundamental, 3rd, 5th and 7th harmonics.
[6 marks]

(iii) Determine the new duty cycle to eliminate the 3rd harmonic.
[5 marks]

b) A capacitor is connected in series to the load in Figure Q4, (R = 20 Ω, L = 30 μH) Calculate the minimum capacitor value so that the inverter output frequency is 3kHz and operates in overlapping mode.
[6 marks]

Continued...

Appendix A

Datasheet Switch 1: NPN BJT Transistor – MJ10023

Absolute Maximum Ratings:

Collector–Emitter Voltage, V_{CEV} 600V
Collector–Emitter Voltage, $V_{CEO(sus)}$ 400V
Emitter–Base Voltage, V_{EBO} 8V
Collector Current, I_C
- Continuous 40A
- Peak 80A

Base Current, I_B 20A
Total Power Dissipation, P_D
- T_C = +25°C 250W
- Derate Above 25°C ..... 1.43W/°C
- T_C = +100°C 143W

Operating Junction Temperature Range, T_J ..... –65° to +200°C
Storage Temperature Range, T_{stg} ..... –65° to +200°C
Thermal Resistance, Junction–to–Case, R_{thJC} ..... 0.7°C/W

Datasheet Switch 2: MOSFET – STW26NM50

Absolute Maximum Ratings:

Symbol	Parameter	Value	Unit
V_{DS}	Drain-source voltage (V_{GS} = 0)	500	V
V_{GS}	Gate-source voltage	±30	V
I_D	Drain current (continuous) at T_C = 25 °C	30	A
I_D	Drain current (continuous) at T_C = 100 °C	18.9	A
I_{DM} (1)	Drain current (pulsed)	120	A
P_{TOT}	Total dissipation at T_C = 25 °C	313	W
	Derating factor	2.5	W/°C
$V_{ESD(G-S)}$	Gate source ESD (HBM-C=100 pF, R=1.5 kΩ)	6000	V
dv/dt (2)	Peak diode recovery voltage slope	15	V/ns
T_{stg}	Storage temperature	-55 to 150	°C
T_j	Max. operating junction temperature	150	°C

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	I_D = 250 µA, V_{GS} = 0	500			V
I_{DSS}	Zero gate voltage drain current (V_{GS} = 0)	V_{DS} = Max rating V_{DS} = Max rating, T_C=125 °C			10 100	µA µA
I_{GSS}	Gate-body leakage current (V_{DS} = 0)	V_{GS} = ± 20 V			± 10	µA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 250 µA	3	4	5	V
$R_{DS(on)}$	Static drain-source on resistance	V_{GS} = 10 V, I_D = 13 A		0.10	0.12	Ω

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$	Turn-on delay time	V_{DD} = 250 V, I_D = 13 A,	-	28	-	ns
t_r	Rise time	R_G = 4.7 Ω V_{GS}=10 V,		15		ns
$t_{d(off)}$	Turn-off-delay time			13		ns
t_f	Fall time			19		ns

Examination Formula Sheet (Rev 4.0)

AC-DC Converters

Single Phase Uncontrolled Rectifiers (Half wave) , R load	Single Phase Uncontrolled Rectifiers (Half wave), RL Load
$V_{o,avg}=\frac{\sqrt{2}V_{S,rms}}{\pi}$, $V_{o,rms}==\frac{V_{S,rms}}{\sqrt{2}}$	$V_{o,avg}=\frac{\sqrt{2}V_{s,rms}}{2\pi}[1-\cos(\beta)]$ $V_{o,rms}=\frac{V_{s,rms}}{\sqrt{2\pi}}\sqrt{\beta-\frac{\sin 2\beta}{2}}\ \beta\approx\pi+\theta\ ,\theta=\tan^{-1}\left(\frac{\omega L}{R}\right)$
Single Phase Uncontrolled Rectifiers (Bridge Full wave)	Three Phase Uncontrolled Rectifiers (Half wave)
$V_{o,avg}=\frac{2\sqrt{2}V_{s,rms}}{\pi}$, $V_{o,rms}=V_{s,rms}$	$V_{o_avg}=\frac{3\sqrt{3}V_{l-n}}{\sqrt{2}\pi}$, $V_{0_rms}=1.19V_{l-n}$
Three Phase Uncontrolled Rectifiers (Full wave)	Single Phase controlled Rectifiers (Half wave)
$V_{0_avg}=\frac{3\sqrt{2}V_{l-l}}{\pi}$, $V_{0_rms}=0.963\ V_{l-l}$	$V_{0_avg}=\frac{V_{S,rms}}{\sqrt{2}\pi}(1+\cos\alpha)$ R Load $V_{0_avg}=\frac{V_{S,rms}}{\sqrt{2}\pi}(\cos\alpha+\cos\beta)$ RL Load
Single Phase controlled Rectifiers (Bridge Full wave)	Three Phase controlled Rectifiers (Half wave)
$V_{0_avg}=\frac{\sqrt{2}V_{S,rms}}{\pi}(1+\cos\alpha)$ R Load $V_{0_avg}=\frac{2\sqrt{2}V}{\pi}\cos\alpha$ RL Load	$V_{0_avg}=\frac{3\sqrt{2}}{2\pi}V_{AN}\left(1+\cos\left(\pi/6+\alpha\right)\right)$
Three Phase controlled Rectifiers (Full wave)	
$V_{0_avg}=\frac{3\sqrt{6}}{\pi}V_{AN}\cos\alpha$	

DC-DC Converters

Buck Converter (CCM)	Buck Converter (DCM)
$V_o=DV_d$ $I_{L\max}=V_o\left[\frac{1}{R}+\frac{(1-D)}{2Lf_s}\right]$ $I_{L\min}=V_o\left[\frac{1}{R}-\frac{(1-D)}{2Lf_s}\right]$	$\frac{V_o}{V_d}=\frac{D}{D+\Delta_1}$ $I_o=\frac{V_dT_s}{2L}D\Delta_1$

Continued...

DC-DC Converters (cont.)

Boost Converter (CCM)	Boost Converter (DCM)
$V_o = \frac{V_d}{1-D}$ $I_{L\max} = \frac{V_d}{(1-D)^2 R} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d}{(1-D)^2 R} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{\Delta_1 + D}{\Delta_1}$ $I_o = \frac{V_d T_s}{2L} D\Delta_1$
Buck-Boost Converter (CCM)	**Buck-Boost Converter (DCM)**
$V_o = \frac{V_d D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{D}{\Delta_1}$ $I_o = \frac{V_d D}{2 f_s L}(D + \Delta_1) - \frac{D I_o}{\Delta_1}$
Flyback Converter (CCM)	**Flyback Converter (DCM)**
$\frac{V_o}{V_d} = \frac{N_2}{N_1}\frac{D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 + \frac{V_d D T_s}{2L_m}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 - \frac{V_d D T_s}{2L_m}$	$\frac{V_o}{V_d} = D\sqrt{\frac{R}{2 f_s L_m}}$ $I_o = \frac{V_o}{R}$

DC- AC Converters

Single-Phase Half-bridge Inverter with RL load	Resonant Converters
$v_o(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Square Wave) $v_o(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Quasi Square Wave) $v(\omega t) = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi}\sin\frac{nD\pi}{2}\cos n(\omega t - \frac{D\pi}{2})$	$\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ $i(t) = \frac{V_s + V_c}{\omega_r L} e^{-\alpha t}\sin\omega_r t \quad , \alpha = \frac{R}{2L}$ $V_c = V_s\left(\frac{e^{2z}-1}{e^{2z}+1}\right), z = \frac{\alpha\pi}{\omega_r}$ $V_{cp} = V_s\left(1 + \frac{2e^{2z}}{e^{2z}+1}\right)$

End of Paper